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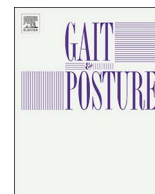
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Full length article

Virtual reality balance training for elderly: Similar skiing games elicit different challenges in balance training



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ABSTRACT

Background: Virtual Reality (VR) balance training may have advantages over regular exercise training in older adults. However, results so far are conflicting potentially due to the lack of challenge imposed by the movements in those games. Therefore, the aim of this study was to assess to which extent two similar skiing games challenge balance, as reflected in center of mass (COM) movements relative to their Functional Limits of Stability (FLOS). **Methods:** Thirty young and elderly participants performed two skiing games, one on the Wii Balance board (Wiiski), which uses a force plate, and one with the Kinect sensor (Kinski), which performs motion tracking. During gameplay, kinematics were captured using seven opto-electronical cameras. FLOS were obtained for eight directions. The influence of games and trials on COM displacement in each of the eight directions, and maximal COM speed, were tested with Generalized Estimated Equations.

Results: In all directions with anterior and medio-lateral, but not with a posterior component, subjects showed significantly larger maximal %FLOS displacements during the Kinski game than during the Wiiski game. Furthermore, maximal COM displacement, and COM speed in Kinski remained similar or increased over trials, whereas for Wiiski it decreased.

Conclusions: Our results show the importance of assessing the movement challenge in games used for balance training. Similar games impose different challenges, with the control sensors and their gain settings playing an important role. Furthermore, adaptations led to a decrease in challenge in Wiiski, which might limit the effectiveness of the game as a balance-training tool.

1. Introduction

Independence at older age is greatly compromised by fall-related injuries. About 40% of those aged 65+ fall at least once per year. About 10–20% of these falls result in hospitalization. The high incidence of falls is attributable to risk factors such as age-related decreases in postural control and strength [1,2]. However, balance training programs can improve postural control and muscle strength and thereby reduce the risk of falls [3–5].

Unfortunately, training effects disappear when training programs are stopped, which indicates a need for on-going training [6–8]. Home based training programs, however, often have poor adherence due to a lack of motivation [9,10]. Virtual Reality (VR) training applications might improve motivation, by introducing a game element. Furthermore, the ability of the VR training to adapt and progress according to

the skill level of the player, ensures the appropriate challenge, therefore conforming to the recommendation to prescribe training for elderly relative to their own capabilities [11].

Despite the advantages of VR training, systematic reviews studying the effectiveness of VR balance training for elderly yielded conflicting results [12–14]. This could be partially attributed to the heterogeneity of the included studies and differences in experimental designs, e.g. comparison of VR training to traditional training or a control group, as well as to the free interpretation of the term VR training. Indeed, VR training encompasses a wide variety of computer-assisted training forms, ranging from off-the-shelf toy games with different controllers, such as the Wii Balance Board, Xbox Kinect and Playstation Eyetoy, to applications specifically designed to be controlled by scientific-grade equipment. The extent to which different types of VR training challenge balance remains unclear.

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Strict guidelines regarding the intensity of balance training are lacking, because intensity is hard to quantify in this context. Moreover, the large variation in movement capabilities and fitness levels in the elderly population, requires intensity to be prescribed relative to an individual's fitness level [11]. Several reviews on the effectiveness of programs to reduce fall risk have proposed general recommendations [6,8,15]. Balance training for elderly has to include strength and balance specific exercises [1,6,15]. More specifically, balance programs should involve a moderate or high challenge to balance, by reducing the Base Of Support (BOS) and introducing weight shifts [6,11,16–18]. Furthermore, the intensity should increase as the individual progresses [6,11].

Medio-lateral (M-L) weight shifting performance has been linked to aging, balance and falls [19,20]. Ski slalom is a sports activity that mainly involves M-L movements, so a VR skiing game has the potential to induce challenging M-L weight shifts towards the limits of stability.

1.1. Aim

The aim of this study was to compare the weight shifts in two similar skiing games using different controllers, currently being used for VR balance training. To this end, we compared Center Of Mass (COM) displacements, expressed as a percentage of participants' functional limits of stability (%FLOS). The game and controller that encouraged players to move more towards their limits of stability, and move faster, was considered most challenging. In addition, we analyzed the trial effect to assess whether the challenge changed after familiarization, and we analyzed whether more movement of the COM in fact led to higher scores to confirm that the game element is an inherently positive stimulus.

2. Methods

2.1. Participants

In this experimental study, we recruited thirty young adults and thirty healthy older adults. All participants volunteered to participate after flyers were distributed around the sports facilities of KU Leuven University. The age range for young adults was 18 to 35. Older adults were aged > 65 years and were community dwelling. All subjects were healthy, meaning that they could stand for at least twenty minutes, had a Mini-Mental state score > 25, did not have severe pathology of the musculoskeletal, neurological or vestibular system, severe cardiovascular disease, diabetes, nor did they use beta-blockers or antidepressants. Subjects signed a written informed consent prior to participation, in accordance with the Declaration of Helsinki. The study was approved by the local ethics committee (Commissie Medische Ethiek K.U. Leuven).

2.2. Materials

Two games were tested: Kinski was played on the Xbox (Microsoft, Redmond, WA, US), using the Xbox Kinect camera to track the player's movements, via depth sensing cameras. The Wiiski game was played using the Wii and its accompanying Balance Board (Nintendo, Kyoto, Japan) registering movements of the Center of Pressure (COP). The objective in both games was to steer an avatar skiing down a slalom track. The time taken to complete the track, plus penalty time for missed gates determined the game score. Participants could change speed by leaning forward or backward, and move from left to right by shifting their weight accordingly. The virtual environment was projected on the same projection screen for all games and tests.

During game play, 3D-kinematics were captured using seven MX-T20 opto-electronical cameras (Vicon, Oxford Metrics, UK) at 100 Hz. Full body COM was calculated in Matlab (MathWorks, New Mexico) based on a 45-markers, 15-segments full-body linked segment model

[21], such that each segment was tracked by at least three markers.

To obtain personalized limits of stability, a dedicated FLOS test was designed to obtain the maximal distance that each subject could move their COM in eight different directions, away from the self-selected upright position, moving as much as possible as a rigid body, without bending the knees, hips or lower back, and without taking a step. The directions specified were anterior-right, right, posterior-right, posterior, posterior-left, left, anterior-left and anterior. COM position was estimated, from 18 markers forming 10 segments that were scaled to participants' anthropometric data and gender [22], and direct feedback was provided on screen during the FLOS task. In post processing, the COM was recalculated based on full body kinematics to determine the functional limit in each direction based on the maximum value of the three trials. The COM displacements obtained during incidental stepping and when lifting the heels were discarded.

An example of the COM trajectory during game play with respect to the participant's FLOS is given in Fig. 1. To quantify the subject specific challenge, the maximum displacement of the COM from the center was calculated and normalised to the displacement during FLOS for each direction. To evaluate the association between the movement of the COM and the game score, the area of the 95% confidence ellipse fitted around the COM trajectory was calculated and the scores were categorized as belonging to the top, middle or lowest tertile. Besides COM displacement, speed affects the extent to which balance is challenged [23]; therefore, we also analyzed peak COM speed.

2.3. Protocol

Participants were screened for exclusion criteria and anthropometric data were obtained. For elderly participants, we administered the Mini Mental State Exam (MMSE). Following the preparations, participants performed the FLOS task three times and played the games in a randomized order, obtained from a computer-based random number generator [24]. Stance width was standardized during the FLOS tasks and both games by markers on the floor and on the Wii balance board. After each game, participants were asked to sit down and take a rest.

2.4. Statistics

A Generalized Estimated Equation (GEE) was used to test whether game, age, group, trial and their interaction effects could explain differences in COM displacements. The GEE was chosen to accommodate data not meeting the assumptions of equal variances and to deal with missing data, for example due to enthusiastic participants who did not succeed to play the game without changing their BOS. Additionally, a GEE was used to test whether the area of the 95% confidence ellipse around the COM trajectory, could predict whether the game score would be in the top, middle or lowest tertile. Finally, a GEE was performed to analyze the effect of the games, group and trials on the peak COM speed. Post-hoc pairwise comparisons were done using Least Significant Difference (LSD). Level of significance was set at $\alpha = 0.05$. The statistics were performed in IBM SPSS Statistics Version 21.0.

3. Results

The characteristics of the participants are summarized in Table 1. GEEs on COM displacement showed that for all directions without a posterior component, a main effect of game was found. The displacements of the COM were significantly larger in all these directions for the Kinski game compared to the Wiiski game (Fig. 1). A summary of all model effects is given in Table 2. Furthermore, maximum COM speed was significantly higher in Kinski compared to Wiiski ($0.54 \text{ m/s} \pm 0.03$ compared to $0.28 \text{ m/s} \pm 0.01$; $p < .001$).

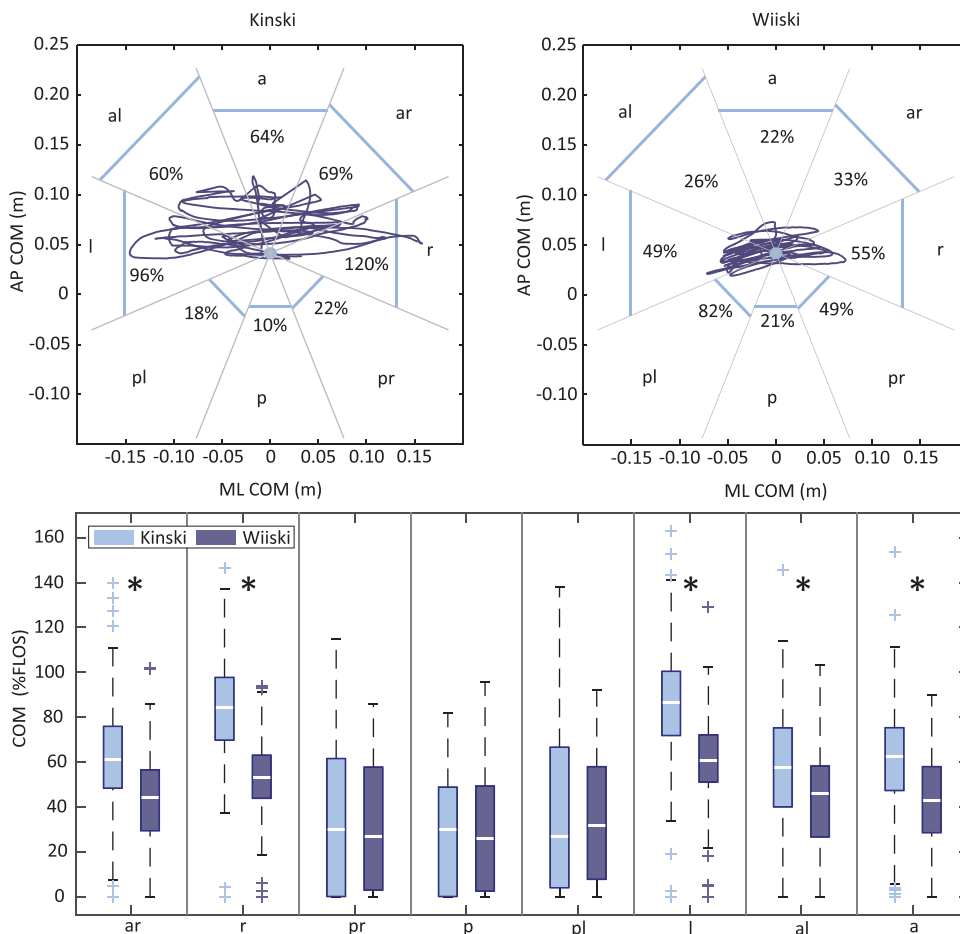


Fig. 1. COM excursion in respect to an individual's FLOS.

In the top panel a typical example of the COM trajectory during Wiiski and Kinski in respect to an individual's FLOS. The light blue external lines represent the functional limits of stability. The dark blue lines show the COM trajectory during gameplay. The dot in the middle indicates the COM location in AP direction during quiet stance. The origin (0,0) is located in the middle between both ankles.

The lower panel shows the summary statistics of the COM displacements expressed in %FLOS for both games, in all directions.

Median values are indicated with a horizontal line, the box ranges from the 1st to the 3rd quartile. Whiskers indicate the range of the data. Significant game effects (*) and outliers (+) are indicated.

3.1. Learning effect

A learning effect, shown by the game x trial interaction, was found for both pure M-L directions: left and right (Fig. 2). Post-hoc analysis for Kinski in the right direction showed significantly larger COM displacements in trial two ($p=.006$) and three ($p=.017$), compared to trial one, whereas for Wiiski, COM displacements decreased from trial one to two ($p < .01$) and showed a trend for trial three ($p=.056$). For the left direction, no trial effect was seen for Kinski. However, for Wiiski again trial two ($p=.001$) and three ($p=.004$) showed significantly smaller COM displacements compared to trial one. Furthermore, COM peak speed was affected by an interaction of game*trial ($p < .020$). For Kinski, trial two ($p=.024$) and three ($p=.038$) elicited higher COM speed than trial one. This trial effect was not present for the Wiiski game.

Table 1
Participants characteristics.

	Elderly	Young
Number	30	30
Age (years)	69.62 \pm 2.8	21.6 \pm 1.4
Female (%)	66.6	66.6
Height (cm)	167.9 \pm 10.3	172.4 \pm 7.5
Weight (kg)	68.08 \pm 11.2	64.33 \pm 8.9
MMSE	29.34 \pm 0.80	

Values are displayed as mean \pm SD. Note that for young subjects we did not employ the MMSE questionnaire.

Table 2
GEE results for all eight directions.

Effect	game	group	trial	game x trial	game x group	group x trial	game x group x trial
Direction							
AR	< .001	.962	.177	.136	.642	.019	.103
R	< .001	.961	.858	< .001	.775	< .001	.828
PR	.111	.024	.240	.144	.197	.318	.495
P	.998	.038	.469	.529	.557	.930	.174
PL	.542	.079	.209	.353	.049	.820	.064
L	< .001	.188	.045	.022	.978	.028	.630
AL	< .001	.849	.148	.558	.582	.257	.333
A	< .001	.592	.341	.891	.045	.153	.038

P-values for all model effects are displayed in the table, significant effects are indicated in bold.

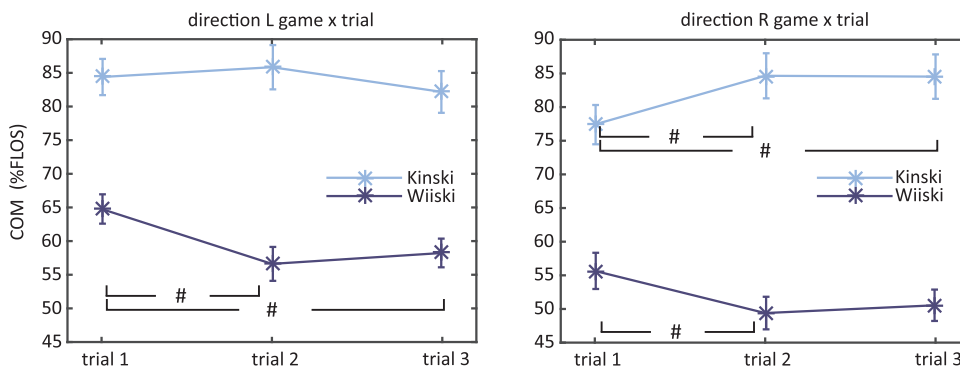


Fig. 2. Game x trial interaction effects for the left and right directions. The lines indicate the progression of the COM displacement in left and right direction over 3 trials. Means and SE are shown. The different shapes indicate different progressions between games. Significant effects ($p < .05$) are marked (#).

3.2. Group differences

A main group effect was found for displacements in the posterior-right and posterior directions. Post-hoc analysis revealed that elderly used larger COM displacements than young did, in both posterior-right, and posterior directions. For the anterior-right, right, and anterior-left directions a significant group x trial interaction was found. Post-hoc analysis for anterior-right revealed that young participants used significantly smaller COM displacements in trials two ($p = .001$) and three ($p = .002$) than in trial one. For the elderly, the trial effect was not significant. For the right direction, post-hoc analysis again showed that young subjects moved significantly less in trial two ($p = .033$) and three ($p = .017$) compared to trial one. A significant difference was also found when focusing on elderly. However, elderly used significantly larger COM displacements in trial two ($p = .002$) and three ($p < .001$) compared to trial one. Post-hoc analysis for the left direction revealed that young participants moved significantly less in trial three ($p < .001$) compared to trial one. Elderly showed no trial effect for this direction.

A significant group x game interaction effect was found for the posterior-left and anterior directions, indicating that elderly responded differently to the games than young subjects. Post-hoc analysis for posterior-left direction revealed that elderly showed significantly larger COM displacements than young when playing Kinski whereas no group differences were present for Wiiski. Furthermore, young subjects showed no game differences whereas elderly used larger COM displacements during Kinski than Wiiski for posterior-left direction. Young and elderly moved significantly more in Kinski compared to Wiiski ($p = .001$). However, the differences between games were larger for elderly (mean: 21.7) than for the young subjects (mean: 12.89). Moreover, during Kinski the elderly used larger anterior COM displacements than the young did, whereas during Wiiski elderly showed smaller displacements in anterior directions than young participants. However, these between group differences did not reach significance within games.

Lastly, for the anterior direction, an interaction effect of all factors was observed. Further analysis revealed, that for young subjects, trial three of Wiiski elicited significantly smaller COM displacements than trial two ($p = .025$), whereas elderly showed no trial effect for the Wiiski game. For the Kinski game there was no trial effect for the young subjects, but for the elderly trial two resulted in larger COM displacements than trial one ($p = .041$).

3.3. Relation between movement and score

The progressions of the scores over trials are shown in Fig. 3 for both games. The GEE showed that the size of the confidence ellipse was dependent on whether the score fell in the higher, mid or lower tertiles for that particular game ($p < .001$). In contrast to our expectation, when movements were larger, as reflected by a larger area of the 95% confidence ellipse, the score was more likely to fall into a lower

category. There were no interaction effects, implying that this effect was consistent over games, groups and trials.

4. Discussion

The main aim of this study was to evaluate weight shifts in two similar skiing games by comparing COM movements relative to the limits of stability, in order to identify the extent to which these games create a challenging situation in terms of balance. For all directions without a posterior component, Kinski elicited larger COM displacements than Wiiski, indicating that Kinski challenges the player more in terms of eliciting COM movements than Wiiski.

4.1. Weight shifts

The differences in COM displacements between both games might be attributable to the different controllers that are used. Large displacements of the COP can be made without actually shifting the body

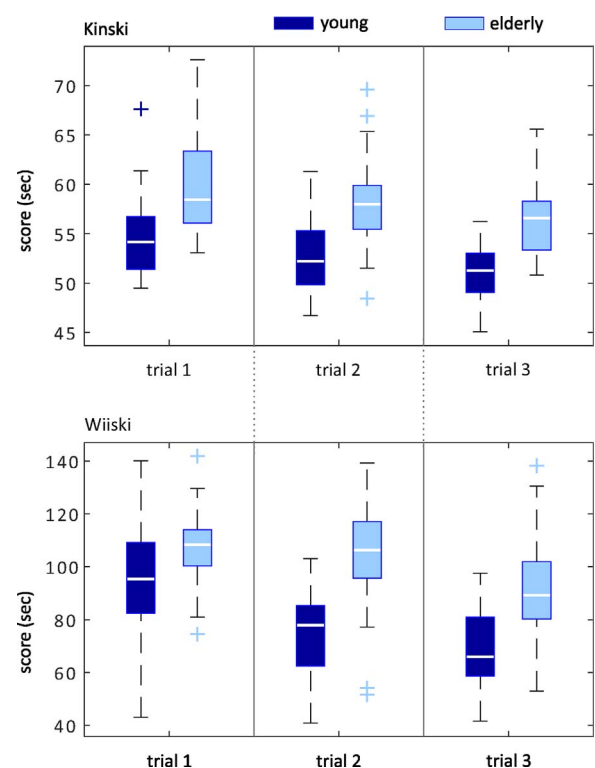


Fig. 3. Score progression over trials. The progression of the scores over trials is shown for both games. Less time depicts a better score. Median values are indicated with a horizontal line, the box ranges from the 1st to the 3rd quartile. Whiskers indicate the range of the data. Outliers are indicated (+).

weight [19,25]. Altering the gain settings between the balance board and the movements of the avatar, by low pass filtering techniques or double integration could bring the COP controller closer to a COM based controller [26]. Furthermore, the gain settings might be further adjusted by implementing the FLOS test, to scale the challenge to the level of the individual and have this evolve with changes in their FLOS. Whereas the type of controller has a big impact on the observed movements, other factors such as the task of the game, specific rewards or penalties and nature of the feedback might also explain differences between games. Besides M-L weight shifts, other directions should not be neglected in a complete balance training programme, as there is evidence for both anterior-posterior (A-P) [27] and M-L [19,28] balance performance to be related with age and falling. These findings suggest that to train balance for all directions a game has to provide sufficient objectives to move in all directions. The lack of incentives to move in posterior direction in both games explains the absence of large displacements in posterior directions. Furthermore, elderly moved more towards their limits in the posterior and posterior-right directions than young subjects, suggesting they aimed to slow down. However, the average, COM displacements in posterior (Wiiski: $\mu 33.21$ %FLOS, Kinski: $\mu 34.28$ %FLOS) and posterior-right directions (Wiiski: $\mu 44.03$ %FLOS, Kinski: $\mu 36.50$ %FLOS) were still small. Young subjects were more eager to go faster, which led to movements predominantly in the anterior direction. Trying to elicit A-P displacements merely by controlling the speed of an avatar through A-P weight shifts, might cause more-experienced players to avoid posterior weight shifts, since they can cope with higher speeds, as observed in the present study. The findings on the COM speed are in line with the findings regarding COM displacements, indicating that Kinski elicits a higher challenge than Wiiski, which even increased over trials.

4.2. Learning effect

Young participants, who were more experienced with computer games than elderly, showed a larger decrease in COM displacements. Furthermore, the game \times trial interaction effects for the M-L direction indicated a steep learning curve. The decrease in COM displacements in left and right direction during the Wiiski game, as participants progressed through trials, was an unwanted effect. From a training perspective, an increasing challenge is desirable [5,11]. In contrast, during the COP-controlled Wiiski game, players learned that they could achieve large COP displacements without actually shifting their weight [19,25]. Furthermore, although VR training is perfectly suitable to adjust the level of the training dynamically to the skills of the participant, the current games used static difficulty settings, which are manually selected.

4.3. Game score

The area of the 95% confidence ellipse around the COM trajectory was correlated to the classification of the score, with more COM movements predicting lower scores. This is highly unwanted, as the score should encourage players to make larger weight shifts and consequently increase the challenge. Furthermore, participants were often presented negative feedback, e.g. a crying avatar. Negative feedback is detrimental for motivation and was shown to be less effective than positive feedback, especially for elderly [29,30]. To encourage players to participate actively in the games, more movement should result in a better score, and feedback should be adequate and encouraging, not demotivating.

4.4. Limitations

The results of the present study indicate that similar games do elicit different COM displacements based on the controllers and game settings. However, the exact threshold that is needed to create sufficient

challenge to enhance balance is unknown. Moreover, the differences in fitness levels in the elderly population suggests a need for training programs tailored to the individuals' abilities [11]. The limit of stability task can be used to obtain personalized difficulty settings with respect to weight shifting ability.

Since balance training for fall prevention requires a multifaceted approach, it is important to study to what extent VR training can challenge all aspects of the balance control system. Introducing large weight shifts should be considered as one of several key elements of balance training, such as muscle training, anticipatory postural adjustments, postural responses, sensory orientation and stability in gait [18]. This implies incorporation of substantial muscle loading, cognitive challenges, transitioning into different poses and taking steps. Future research should assess to which extent these aspects are challenged in VR training applications.

5. Conclusions

Two similar and often used VR training interventions were compared with respect to the movements of the COM they elicit in different directions. We found that the Kinski game elicited larger COM displacements than the Wiiski game. Therefore, to challenge balance by means of larger weight shifts, we recommend Kinski with a controller that uses kinematics over Wiiski that uses COP. To cover the multifaceted challenges of balance training, further research should be done to be able to provide a comprehensive VR training package, which is tailored to the individual's level. More specifically, personalized and adaptive difficulty settings, a feature currently lacking, should be considered to retain sufficient challenge with increasing individual performance levels. Moreover, greater COM movement should be rewarded with a higher game score, to create a more challenging and motivating VR Training experience. More importantly, off the shelf games need to be optimized to incorporate challenging weight shifts to train balance in healthy elderly.

Conflict of interest

We can confirm that there are no conflicts of interest for any of the authors. The funding was not involved in either study design or data analysis.

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